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**MULTIMODE OPERATION
OF
QUADRATURE PHASED ARRAY MR COIL SYSTEMS**

CROSS-REFERENCE TO RELATED APPLICATION

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- [1] This application claims the benefit of U.S. Provisional Application No. 60/109,820, filed November 25, 1998.

BACKGROUND OF THE INVENTION

- 1003245-3100*
- [2] The advantages of using phased array or multi-coil MR coil systems to enhance magnetic resonance imaging and spectroscopy are well known. A situation facing the designer of such coils is the finite number of available simultaneous data acquisition channels in the host MR system; frequently, there are only four channels, sometimes known as receivers, in the host system.
- [3] Another issue is the reconstruction time to create the images from the collected data; processing multiple channels to form a single image increases the time needed by the magnetic resonance imaging system to process the data, by two or three dimensional Fourier Transform techniques or other methods, to create the final images. Another consideration is the fact that data acquisition hardware with additional performance capabilities may only be available on one receiver, or on fewer than the total number of available receivers.

SUMMARY OF THE INVENTION

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- [4] Reconstruction of an image from two quadrature modes of a specific phased array coil element via two separate data acquisition channels [or receivers] provides the best possible image signal to noise ratio and uniformity, since the data can always be reconstructed in the most optimum way. However, the use of two separate receivers for the two quadrature signals from a specific phased array coil element may cause problems with reconstruction time, or limitations due to the finite number of available receivers. Thus, there may be conditions when combining the two quadrature signals at the RF level into a single signal may be most advantageous, and other times when processing the two RF signals independently via two separate data acquisition receivers may be the best scheme.
- [5] The present invention allows the two quadrature signals to be acquired as a single signal, precombined at the RF level within the coil interface, or as two separate RF signals by two of the receivers of the phased array hardware. It also provides a means for remote selection of the mode of operation from the operator's console when the system is used with a MRI system, such as the GEMS Signa system.

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BRIEF DESCRIPTION OF THE DRAWINGS

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- [6] The preferred embodiments of the present invention are illustrated by way of example, and not limitation, in the figures of the accompanying drawings, in which:
- [7] Figure 1 is wire model of a phased array neurovascular coil;
- [8] Figures 2A and 2B are electrical schematics of a coil interface circuit that provides multimode operation of the phased array neurovascular coil shown in Figure 1;
- [9] Figure 3 is a wire model of the phased array neurovascular coil in a first operational mode;
- [10] Figure 4 is a wire model of the phased array neurovascular coil in a second operational mode; and
- [11] Figure 5 is a wire model of the phased array neurovascular coil in a third operational mode.
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DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS OF THE INVENTION

[12] The presently preferred embodiments of the invention will now be described with reference to the Figures, in which like elements are referred to by like numerals. A number of specific applications of a preferred embodiment are discussed. In particular, the multimode operation of a neurovascular coil designed for and operating on the General Electric Medical Systems Signa MRI system is described; however, the preferred embodiments may be applied to other coils and other systems by those skilled in the art after reviewing this detailed description.

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[13] Figure 1 is wire model of a phased array neurovascular coil 50, also referred to herein as a neurovascular array coil. The neurovascular array coil 50 contains four separate imaging coils. The first coil is a quadrature tapered birdcage 60 covering the brain and head. Further details regarding the quadrature tapered birdcage are provided in U.S. application No. _____, atty ref. No. 99,443-A, November 24, 1999, the contents of which are incorporated herein by reference. The first coil may alternatively be in the form of a domed birdcage, such as is described in US Patent No. 5,602,479, the contents of which are incorporated herein by reference, although the tapered birdcage is preferred because it provides improved field homogeneity on the XZ and YZ image planes.

[14] The second coil is formed from two posterior cervical spine coils 70, the outputs of which are preferably combined at the RF level. The third and fourth coils are a superior anterior neck coil 80 and an inferior anterior neck coil 90. In accordance with an alternative embodiment, the outputs of the two posterior cervical spine coils 70 are not combined at the RF level and a single anterior neck coil (not shown) replaces the neck coils 80 and 90.

[15] In accordance with a preferred embodiment, the superior anterior neck coil 80 and the inferior anterior neck coil 90 are mounted in an adjustable manner. For example, referring to Figure 1, the neck coils 80 and 90 may be housed in a support structure 85, as is known to those skilled in the art. In a preferred embodiment, the support structure 85 is mounted in a hinged manner, with the hinge location being toward the superior end of the support structure 85. When mounted in this manner, the inferior end of the support structure 85 may be raised and/or lowered, depending upon the size of the test subject, and may rest on the chest area of the test subject. This provides the advantage of locating the neck coils 80 and 90 as close to the test

subject as possible, thereby improving image quality over embodiments in which the neck coils 80 and 90 are fixedly located.

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[16] Figures 2A and 2B are electrical schematics of a coil interface circuit 100 that provides multimode operation of the phased array neurovascular coil 50 shown in Figure 1. The coil interface circuit 100 couples the phased array neurovascular coil 50 to a magnetic resonance imaging system. The coil interface circuit 100 has a number of signal input points 102, which are coupled to receive MR signals from the phased array neurovascular coil 50. As shown in Figure 2A, signal inputs 102 are coupled to output ports, port #2, port #3, port #4, port #5, and port #6, which are in turn coupled to predetermined MRI system receivers. Many systems, including the GEMS Signa system, provide only four receiver channels. Thus, because all the signal inputs 102 cannot simultaneously be applied to the MRI system receivers when the number of potential signal inputs 102 exceeds the number of receivers, the interface circuit 100 allows selected signal inputs 102 to be coupled to the MRI system receivers.

[17] Selection of the operational modes of the phased array neurovascular coil 50 is made in the coil interface unit 100 by the use of PIN diode RF switches, as further described below. The following table defines the relationship between signal inputs 102 to the coil interface 100 and outputs, e.g., port #2-6, from the coil interface 100.

SIGNAL	SMB	SYSTEM PORT	SYSTEM RECEIVER
Head I	P5	5	0
Head Q (high res)	P4	6	1
Head Q (high speed)	P4	5	0
C-Spine	P7	4	3
ANT SUP	P6	3	2
ANT INF	P8	2	1

[18] In the table above, Head I refers to the in-phase MR signal from the birdcage coil 60, Head Q refers to the quadrature MR signal from the birdcage coil 60, C-Spine refers to the combined MR signals from the posterior cervical spine coils 70, ANT SUP refers to the MR signal from the superior anterior neck coil 80, and ANT INF refers to the MR signal from the inferior anterior neck coil 90.

[19] As shown in Figure 2A, the coil interface 100 is coupled to DC power supplies, +15V and -15V, from the MRI system. The electrical schematic of Figure 2A also includes a number of inductors, each labeled as "RFC," that function as RF chokes. The RF chokes are preferably self-resonant at approximately 63.87 MHz. For example, the RF chokes may be obtained from J. W. Miller, part no. RFC-50.

[20] The birdcage coil 60 and the coil interface 100 are designed so that the two quadrature signal components from this coil element may selectively be combined into a single signal for simultaneous use with the other three coil elements. This provides coverage of the entire volume within the quadrature neurovascular array 50 using a total of four simultaneous data acquisition channels [receivers] from the MRI system. In addition, by combining the two quadrature signal components, a preferred embodiment allows for applications employing a single FAST receiver, where only one of the available phased array receivers has the FAST data acquisition capability.

[21] When the brain or the brain, brain stem, and cervical region of the spinal cord, for example, are to be imaged with the highest possible image signal to noise ratio and uniformity, another mode may be used. Specifically, the coil interface 100 directs the two quadrature components of the MR signal from the tapered birdcage coil element 60 into two separate receivers for optimum results. An advantage of this feature is that it preserves the ability to simultaneously cover the entire region from the aortic arch to the top of the head in one phased array acquisition, enables the use of one high performance receiver channel for complete acquisition of images from the brain, and yet enables the highest degrees of resolution, signal to noise ratio, and uniformity to be obtained from the brain, and associated neurological areas of interest by acquiring the data from the two quadrature modes of the tapered birdcage coil element through two separate receivers.

[22] The coil interface 100 supports distinct imaging functions by automatic selection of the optimum assembly of the array coil elements. As described below, the coil interface 100 may be remotely configured, i.e., the state of one or more PIN diode RF switches may be set, based upon inputs from the MRI system console. Examples of distinct imaging modes that may be supported by a coil interface, such as the coil interface shown in Figures 2A and 2B, include: NEUROVASCULAR, HIGH RESOLUTION BRAIN, HIGH SPEED BRAIN, HIGH RESOLUTION BRAIN AND CERVICAL SPINE, CERVICAL SPINE, and VOLUME NECK.

- [23] Each of these modes is preferably activated by selecting the appropriate Coil Name from the coil selections on the console of the host MRI system when prescribing the scan. By way of the coil interface 100, the needed coils and the signal combining method are activated for the selected mode, and the unused coil elements are electronically disabled to optimize image quality and minimize artifacts. Each mode has a distinct method of operation as described below.

NEUROVASCULAR Mode

- [24] In NEUROVASCULAR mode, all of the coil elements in the phased array neurovascular coil 50 are active, and the birdcage coil 60 operates in quadrature with the two signals combined to drive a single receiver. Specifically, the coil interface 100 includes a combiner circuit, including a switch and a phase shifter, that is set to combine the in-phase, or "I," output and the quadrature, or "Q," output of the birdcage coil 60 before applying the signal to the MRI system preamplifier at port #5. The two posterior spine coils 70 drive a single receiver, such as port #4. The superior anterior neck coil 80 and the inferior anterior neck coil 90 each drive a separate receiver, such as ports #3 and #2, respectively. Thus, in NEUROVASCULAR mode, the coil interface 100 provides a total of four simultaneous data acquisitions, the maximum number of simultaneous data acquisitions that can be handled by the MRI system. Since the coverage volume is large, the signal to noise ratio performance of the head portion of the coverage may be slightly reduced, by the combination of the I and Q outputs of the birdcage coil 60, to allow only one receiver channel to be used to cover the head region.

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- [25] Figure 3 is a wire model of the phased array neurovascular coil 50 in NEUROVASCULAR mode. As noted above and shown in Figure 3, all elements of the phased array neurovascular coil 50 are activated and the MRI system operates in the phased array mode. The NEUROVASCULAR mode may be used for all types of brain and neck imaging, other than Echo Planar Imaging. The NEUROVASCULAR mode is particularly useful for brain and/or cervical spine localizers, imaging of the cervical spine, imaging of the carotid arteries, and imaging of the aortic arch. The preferred embodiment shown in Figure 3 advantageously provides a field of view of up to 46 cm.

HIGH RESOLUTION BRAIN Mode

- [26] In HIGH RESOLUTION BRAIN mode, the two quadrature components of the MR signal from the birdcage coil 60 each drive a separate receiver channel on the MRI system, providing optimum uniformity and signal to noise ratio performance. Specifically, the coil interface 100 couples the I and Q signals from the birdcage coil 60 to separate receiver ports on the MRI system, such as ports 5 and 6, as shown in Figure 2A and the table above. The combiner circuit in the coil interface 100 is electrically disconnected to allow independent reconstruction of the data from the two channels. The posterior cervical spine coils 70 and the anterior neck coils 80 and 90 are electrically disabled to minimize artifacts and undesirable coil interactions. Since the highest possible degree of signal to noise ratio and uniformity are desired, but coverage of the entire volume of the coil is not needed, two separate receivers are used for the birdcage coil 60 MR signal. Techniques for electrically disabling an imaging coil are well known to those skilled in the art.

- [27] Figure 4 is a wire model of the phased array neurovascular coil in HIGH RESOLUTION BRAIN imaging mode. As shown in Figure 4, only the quadrature birdcage coil 60 is activated; the cervical spine coils 70 and the anterior neck coils 80 and 90 are electrically disabled. The MRI system operates in phased array mode. The HIGH RESOLUTION BRAIN imaging mode may be used for all types of brain and/or head imaging, other than echo planar imaging, but is especially useful for high resolution studies of the brain. The HIGH RESOLUTION BRAIN imaging mode is also useful for high resolution Circle of Willis imaging. The preferred embodiment shown in Figure 4 provides a field of view of up to 24 cm.

HIGH SPEED BRAIN Mode

- [28] The HIGH SPEED BRAIN mode routes the two quadrature modes of the head birdcage resonator 60 through the combiner circuit in the coil interface 100 to produce one signal containing the signal from both quadrature modes. In Figure 2A, the combined signal is provided to the MRI system at port #5. The combined signal drives one channel of the phased array system [preferably Receiver 0 (Receiver selection 1 on LX systems) for the GEMS Signa system] to minimize reconstruction time or to allow the use of a single FAST receiver. All other coil elements are electrically disabled.

[29] Figure 5 is a wire model of the phased array neurovascular coil 50 in HIGH SPEED BRAIN mode. Like Figure 4, only the quadrature birdcage coil 60 is activated; the cervical spine coils 70 and the anterior neck coils 80 and 90 are electrically disabled. The HIGH SPEED BRAIN mode may be used for Echo Planar Imaging and/or vascular or other studies of the brain where decreased acquisition time is desirable. HIGH SPEED BRAIN mode is also useful for imaging the Circle of Willis.

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[30] Additional modes of operation for the phased array neurovascular coil 50 may be used by providing the MRI system with the appropriate port masks for the coil interface 100. For example, embodiments of the phased array neurovascular coil 50 may also acquire images from one or more of the following operational modes: HIGH RESOLUTION BRAIN AND CERVICAL SPINE, CERVICAL SPINE and VOLUME NECK. Each of these modes is described in further detail below. For these alternative embodiments, unless otherwise noted, it is assumed that the cervical spine coils 70 are applied separately to the coil interface, rather than being combined at the RF level, and the anterior neck coils 80 and 90 are either combined to provide a single input to the coil interface or replaced by a single anterior neck coil.

HIGH RESOLUTION BRAIN AND CERVICAL SPINE Mode

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[31] This mode activates the head and posterior cervical spine coils, and disables the anterior neck coil. This allows focal studies of the brain, brain stem, spinal cord, and cervical spine. The two quadrature components of the MR signal from the birdcage coil 60 each drive a separate receiver channel for optimum uniformity and signal to noise ratio performance. The combiner circuit is electrically disconnected to allow independent reconstruction of the data from the two channels. The two posterior cervical spine coils 70 also each drive a separate receiver channel.

CERVICAL SPINE Mode

[32] In CERVICAL SPINE mode, the two quadrature components of the MR signal from each of the two posterior cervical spine coil elements 70 each drive a separate receiver channel for optimum uniformity and signal to noise ratio performance. The head coil element 60 and the anterior neck coil 80, 90 are electrically disabled to minimize artifacts and undesirable coil interactions.

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Year	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
Population	1,000,000	1,050,000	1,100,000	1,150,000	1,200,000	1,250,000	1,300,000	1,350,000	1,400,000	1,450,000	1,500,000	1,550,000	1,600,000	1,650,000	1,700,000	1,750,000	1,800,000	1,850,000	1,900,000	1,950,000	2,000,000	2,050,000	2,100,000	2,150,000	2,200,000	2,250,000	2,300,000	2,350,000	2,400,000	2,450,000	2,500,000	2,550,000	2,600,000	2,650,000	2,700,000	2,750,000	2,800,000	2,850,000	2,900,000	2,950,000	3,000,000	3,050,000	3,100,000	3,150,000	3,200,000	3,250,000	3,300,000	3,350,000	3,400,000	3,450,000	3,500,000	3,550,000	3,600,000	3,650,000	3,700,000	3,750,000	3,800,000	3,850,000	3,900,000	3,950,000	4,000,000	4,050,000	4,100,000	4,150,000	4,200,000	4,250,000	4,300,000	4,350,000	4,400,000	4,450,000	4,500,000	4,550,000	4,600,000	4,650,000	4,700,000	4,750,000	4,800,000	4,850,000	4,900,000	4,950,000	5,000,000	5,050,000	5,100,000	5,150,000	5,200,000	5,250,000	5,300,000	5,350,000	5,400,000	5,450,000	5,500,000	5,550,000	5,600,000	5,650,000	5,700,000	5,750,000	5,800,000	5,850,000	5,900,000	5,950,000	6,000,000	6,050,000	6,100,000	6,150,000	6,200,000	6,250,000	6,300,000	6,350,000	6,400,000	6,450,000	6,500,000	6,550,000	6,600,000	6,650,000	6,700,000	6,750,000	6,800,000	6,850,000	6,900,000	6,950,000	7,000,000	7,050,000	7,100,000	7,150,000	7,200,000	7,250,000	7,300,000	7,350,000	7,400,000	7,450,000	7,500,000	7,550,000	7,600,000	7,650,000	7,700,000	7,750,000	7,80																																																																

[35] In view of the wide variety of embodiments to which the principles of the present invention can be applied, it should be understood that the illustrated embodiments are exemplary only, and should not be taken as limiting the scope of the present invention. For example, the steps of the design method may be taken in sequences other than those described, and more or fewer elements may be used than are described. In addition, although reference is made herein to

